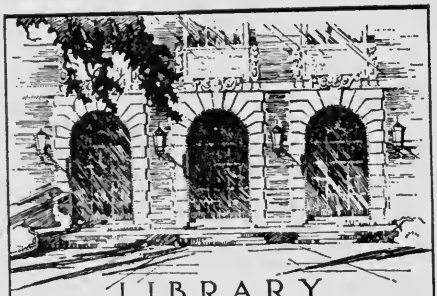
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# FERTILIZER EXPERIMENTS WITH GREENHOUSE LETTUCE AND TOMATOES

By J. W. Lloyd

URBANA, ILLINOIS, FEBRUARY, 1927

## SUMMARY

The experiments in the production of greenhouse lettuce and tomatoes reported in this bulletin were designed primarily to test the effectiveness of various forms of commercial fertilizer as supplements to a soil mixture of 4 parts brown silt loam, 2 parts rotted manure, and 1 part sand. However, for purposes of comparison two other soil mixtures were used, and also the effect of steam sterilization of greenhouse soil was tested. Four crops of lettuce and one crop of tomatoes were grown each year.

The 4-2-1 soil mixture supplemented with nitrate of soda or with dried blood produced better average yields of lettuce than the untreated 4-4-1 soil mixture (4 parts brown silt loam, 4 parts rotted manure, 1 part sand), and fully as good average yields of tomatoes.

The addition of acid phosphate to the nitrate treatment reduced the yields of lettuce but increased the yields of tomatoes. However, when lime was added to the nitrate and acid phosphate in treating the 4-2-1 soil mixture, the detrimental effect of the acid phosphate on the lettuce was overcome and the high yield of tomatoes maintained.

Another way in which the detrimental effect of acid phosphate on the lettuce was avoided was by using nitrate alone on the 4-2-1 soil mixture for producing the lettuce, and then applying a top-dressing of acid phosphate for the tomatoes after the lettuce was harvested. This treatment produced considerably higher average yields in both lettuce and tomatoes than the 4-4-1 soil mixture without commercial fertilizer, and nearly as high a combined yield of lettuce and tomatoes as the 4-4-1 soil mixture treated with nitrate for the lettuce and acid phosphate and potassium sulfate for the tomatoes.

Steam sterilization of the 4-4-1 soil mixture increased the yield of lettuce but so decreased the yield of tomatoes that the combined yield of the two crops was considerably less than from the unsterilized soil of the same composition, and also much less than from the 4-2-1 mixture treated with nitrate alone.

In the light of these experiments it is recommended that in growing a combined crop of greenhouse lettuce and tomatoes on brown silt loam in raised benches, a 4-2-1 soil mixture be employed, and that this soil be fertilized by using nitrate of soda (approximately .86 of a pound per 100 square feet of bench space) before planting each crop of lettuce, and by applying a top-dressing of acid phosphate (approximately 2.3 pounds per 100 square feet of bench space) for the tomatoes after the last crop of lettuce for the season has been harvested.

# FERTILIZER EXPERIMENTS WITH GREENHOUSE LETTUCE AND TOMATOES

By J. W. Lloyd, Chief in Olericulture

Greenhouse vegetable growers in Illinois have in the past depended upon stable manure almost entirely as a fertilizer for lettuce and tomatoes. During the last few years, however, it has become more and more difficult to get supplies of manure, and growers have been looking for a method of producing these crops without the use of as large quantities as formerly.

A previous experiment at the Illinois Station,[1] in which garden loam (brown silt loam), rotted manure, and sand were combined in different proportions for the growing of greenhouse lettuce and tomatoes, had shown that with every increase in the proportion of manure in the soil mixture there was an increase in yield. However, the soil composed of 4 parts garden loam, 2 parts rotted manure, and 1 part sand (by volume) gave good yields and contained sufficient humus to be fairly friable and retentive of moisture.

The essential physical conditions for good growth of crops apparently being supplied by this amount of manure, the problem became one of ascertaining whether the plant-food materials in the mixture might be satisfactorily supplemented by commercial fertilizing materials so as to provide for the needs of maximum crops. Taking the 4-2-1 soil mixture as standard, therefore, commercial fertilizing materials containing nitrogen, potassium, and phosphorus were applied to different greenhouse plots and the yields resulting from the different treatments recorded.

A comparison was also made between soil mixtures containing different proportions of manure, both with and without commercial fertilizers, and a test was included to determine the effect of sterilizing a greenhouse soil with steam previous to the planting of each crop of lettuce. The steam sterilization was originally planned to aid in disease control, but as there was very little damage from disease in any of the plots, its effect on the yields of lettuce was of more significance.

The first series of experiments in using commercial supplements to manure for the growing of greenhouse lettuce and tomatoes were conducted for three years. The results, reported on pages 317 to 328, indicated that certain treatments favorable to the production of large yields of tomatoes were detrimental to the lettuce crop, while other treatments favorable to lettuce were unfavorable to tomatoes. There-

[1] Unpublished data in experiment by C. E. Durst and H. D. Brown.

fore, further tests were planned with a view to finding, if possible, a combination of treatments that would be effective in producing large yields of both crops. These are reported in the last section of the bulletin, on pages 328 to 336.

## METHOD OF CONDUCTING THE EXPERIMENTS

The tests were made in the west greenhouse of the vegetable range at this Station. The house, which is 28 by 50 feet, is provided with both ridge and side ventilation and equipped with four benches. Three of the benches were used for the different soil treatments, while part of the fourth was employed for growing the young plants preparatory

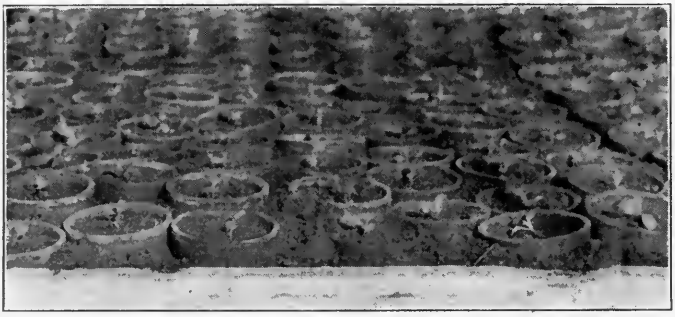

FIG. 1.—LETTUCE SEEDLINGS SOON AFTER BEING SHIFTED TO 2½-INCH POTS

With both lettuce and tomatoes, the seed was sown in flats and the young seedlings shifted to 2½-inch pots as soon as the plants were large enough to handle. The soil used in the pots was in all cases a mixture of 4 parts garden loam, 2 parts manure, and 1 part sand.

to setting them in the differently treated soil mixtures. The benches were 47 inches wide, inside measure, and were divided by cross partitions into sections 6 feet long, so that the area of each section was approximately 24 square feet. The depth of the benches was 6⅔ inches.

In preparing the soil mixture, garden loam and rotted manure were pulverized by passing the loam thru a half-inch screen and the manure thru a manure shredder. The loam, manure, and sand were then thoroly mixed by repeated shoveling, and the mixture was placed in the benches, which were filled slightly above the level of the sides. The soil was smoothed off with a straight edge without being compacted. After being wet down and prepared for planting, the top of the soil was slightly below the edge of the bench, thus leaving sufficient space for watering.

Each season four crops of Grand Rapids lettuce and a spring crop of tomatoes were grown. At the close of the tomato harvest each year the benches were cleaned out completely and an entirely new lot of soil put in for the next season's work.

*Method of Applying Fertilizers.*—In applying the fertilizer the ingredients for each section were weighed separately, ground in a mortar, and sprinkled carefully by hand over the surface of the soil in the given section of bench. The material was then thoroly mixed with the

TABLE 1.—QUANTITIES OF FERTILIZER APPLIED TO SOIL IN EXPERIMENTS WITH GREENHOUSE LETTUCE AND TOMATOES

| Fertilizer | Amounts applied[1] | | |
|---|---|---|---|
| | Per section | Rate per 100 square feet | Rate per acre |
| | *grams* | *lbs.* | *lbs.* |
| Nitrate of soda | 94 | .860 | 375 |
| Dried blood | 432 | 3.966 | 1 728 |
| Potassium sulfate | 125 | 1.147 | 500 |
| Acid phosphate | 250 | 2.295 | 1 000 |
| Steamed bone | 250 | 2.295 | 1 000 |
| Lime | 500 | 4.591 | 2 000 |

[1]In a few sections double the above quantities of nitrate of soda, potassium sulfate, and acid phosphate were used.

With the exception of the nitrate, only one application was made for the season's cropping, which consisted of four crops of lettuce and one crop of tomatoes. In the case of the nitrate the quantity specified was usually applied previous to the planting of each lettuce crop, so that the application for the entire season ordinarily consisted of four times the quantity here shown.

soil by means of trowels. The fertilizer, except the nitrate of soda, was usually applied and worked into the soil several days before the planting was to be done. The nitrate ordinarily was applied not more than 24 hours before the planting. As soon as one crop of lettuce was harvested, the soil was dug up with a hoe and leveled with a rake, the nitrate applied, and another crop started if the plants were large enough for setting. Occasionally it was necessary to wait a few days for the plants to develop to the proper size and condition for setting. Usually, however, very little time was lost between the harvesting of one lettuce crop and the planting of another.

The quantities of fertilizer applied, whether used alone or in combination, were in most instances as given in Table 1.

*Temperature of the House.*—After the warm weather of early fall was over, so that it was possible to control the temperature in the

house, the following schedule of temperatures was maintained in the lettuce house until the third crop was harvested: night, 50° F.; cloudy day, 55° F.; clear day, 60-65° F. When the fourth crop of lettuce, which was interplanted with tomatoes, was put on the benches, the temperature was raised 5 degrees. After the fourth crop of lettuce was harvested and the tomatoes occupied the benches alone, the tem-

FIG. 2.—LETTUCE NEARLY READY TO HARVEST

The lettuce was harvested when the most advanced plants had reached prime condition for market. All the harvesting was done in the morning, and whenever possible on a cloudy day, in order to lessen the variation in weights caused by differences in turgidity of lettuce harvested at different hours of the day and at different temperatures.

perature was raised to the following schedule: night, 65° F.; cloudy day, 70° F.; clear day, 75-80° F.

*Growing the Seedling Plants.*—For growing the plants of both lettuce and tomatoes, the seed was sown in flats and the young seedlings were shifted to 2½-inch pots as soon as the plants were large enough to handle. The potting soil used was in all cases the 4-2-1 mixture described on page 311. The pots were plunged to their rims in the soil of a greenhouse bench. The lettuce plants were transplanted from the 2½-inch pots to the benches, but the tomato plants were shifted to 4-inch pots before being benched. When conditions were favorable, the seed for the first crop of lettuce was sown from August 19 to 25. For the succeeding crops a new batch of seed was sown at about the time the plants of the preceding crop were placed on the benches. The tomato seed was sown at or about the same date as the lettuce for the fourth crop.

*Distance of Planting.*—The soil of each section was marked off in checks 8 inches apart, and a lettuce plant was placed at each intersection. Each section thus accommodated six rows of 9 plants each, or a total of 54 plants. When the tomatoes were interplanted in the lettuce, 4 lettuce plants were omitted from the second row and 4 from the fifth row, and tomato plants were substituted for them. Thus for the fourth crop there were 46 lettuce plants and 8 tomato plants in each section.

FIG. 3.—TOMATO PLANT IN 4-INCH POT, READY TO SET IN BENCH

The lettuce plants were transplanted from the 2½-inch pots to the benches, but the tomato plants were shifted to 4-inch pots before being benched.

*Care of the Growing Crops.*—The crops were carefully watered and cultivated as often as was necessary. The soil without manure required more frequent watering than that with manure. After the lettuce had begun to cover the benches, the hose was handled in a manner to avoid wetting the leaves. Fumigation for the control of aphids and white fly was resorted to whenever conditions demanded it.

The tomatoes were pruned to single stems, and were trained to perpendicular cords fastened to wire loops that extended thru the cracks between the bottom boards of the benches, where they were anchored by means of small wooden blocks. The tops were tied to horizontal wires supported by the framework of the house. The vines were tied to the upright cords by means of soft twine. Hand pollination was resorted to in order to insure setting of the fruit.

*Harvesting.*—When the most advanced lettuce had reached prime condition for market, the entire crop was harvested. The plants were cut off at the surface of the ground, and any dried or yellow leaves were removed. The net trimmed lettuce from each section was weighed separately and the yield recorded. The weights of the four crops from a given plot were added to determine the yield for the season.

The harvesting was invariably done in the morning, and whenever possible a cloudy day was chosen, so that there might be less variation in weights due to differences in the turgidity of lettuce at different hours of the day and at different temperatures.

TABLE 2.—DATES OF SOWING, SHIFTING, BENCHING, AND HARVESTING LETTUCE

| Season | First Crop | | | | Second Crop | | | |
|---|---|---|---|---|---|---|---|---|
| | Sown | Shifted | Benched | Cut | Sown | Shifted | Benched | Cut |
| 1918-19 | Aug. 19 | Sept. 4 | Sept. 24 | Nov. 1 | Sept. 26 | Oct. 7 | Nov. 2 | Dec. 23 |
| 1919-20 | Sept. 19 | Oct. 3 | Oct. 24 | Dec. 12 | Oct. 25 | Nov. 12 | Dec. 16 | Feb. 19 |
| 1920-21 | Aug. 25 | Sept. 11 | Sept. 27 | Nov. 5 | Sept. 28 | Oct. 18 | Nov. 13 | Jan. 13 |
| 1921-22 | Aug. 17 | Aug. 29 | Sept. 27 | Nov. 4 | Sept. 27 | Oct. 11 | Nov. 5 | Jan. 10 |
| 1922-23 | Aug. 19 | Aug. 28 | Sept. 22 | Oct. 26 | Sept. 22 | Oct. 5 | Oct. 28 | Dec. 21 |
| 1923-24 | Aug. 18 | Aug. 28 | Sept. 27 | Nov. 6 | Sept. 24 | Oct. 8 | Nov. 7 | Jan. 15 |
| | Third Crop | | | | Fourth Crop | | | |
| Season | Sown | Shifted | Benched | Cut | Sown | Shifted | Benched | Cut |
| 1918-19 | Nov. 13 | Nov. 29 | Dec. 28 | Feb. 21 | Dec. 28 | Jan. 14 | Feb. 22 | Apr. 4 |
| 1919-20 | Dec. 15 | Jan. 12 | Feb. 23 | Apr. 8 | Feb. 19 | Mar. 10 | Apr. 10 | May 12 |
| 1920-21 | Nov. 15 | Dec. 3 | Jan. 18 | Mar. 10 | Jan. 14 | Jan. 29 | Mar. 2 | Apr. 14 |
| 1921-22 | Nov. 5 | Nov. 21 | Jan. 11 | Mar. 3 | Jan. 11 | Jan. 28 | Mar. 4 | Apr. 7 |
| 1922-23 | Oct. 26 | Nov. 11 | Dec. 23 | Feb. 23 | Dec. 22 | Jan. 7 | Feb. 24 | Apr. 3 |
| 1923-24 | Nov. 7 | Nov. 26 | Jan. 16 | Mar. 13 | Jan. 15 | Feb. 4 | Mar. 15 | Apr. 22 |

The tomatoes were harvested twice a week, beginning as soon as there were any ripe fruits and continuing as long as there were any fruits of marketable quality. After each picking they were graded

TABLE 3.—DATES OF SOWING, SHIFTING, BENCHING, AND HARVESTING TOMATOES

| | 1918-19 | 1920 | 1921 | 1922 | 1922-23 | 1924 |
|---|---|---|---|---|---|---|
| Seed sown | Dec. 28 | Feb. 19 | Jan. 14 | Jan. 11 | Dec. 28 | Jan. 12 |
| Shifted to 2½-inch pots | Jan. 6 | Mar. 8 | Jan. 29 | Jan. 30 | Jan. 7 | Jan. 26 |
| Shifted to 4-inch pots | Feb. 8 | Apr. 1 | Feb. 23 | Feb. 18 | Feb. 3 | Feb. 25 |
| Benched | Feb. 22 | Apr. 10 | Mar. 12 | Mar. 4 | Feb. 24 | Mar. 15 |
| First picking | May 13 | June 18 | May 17 | May 12 | May 4 | May 27 |
| Last picking | July 30 | Aug. 30 | July 27 | Aug. 1 | July 31 | Aug. 12 |
| Duration of harvest | 78 days | 73 days | 71 days | 81 days | 88 days | 77 days |

into No. 1's, No. 2's, and culls, consideration being given to size, shape, and smoothness. The No. 1's and No. 2's were marketed together as a single grade, and met with ready sale in the local market.

The dates of sowing, shifting, benching, and harvesting the various crops of lettuce and tomatoes are given in Tables 2 and 3.

## COMMERCIAL FERTILIZERS TESTED AS SUPPLEMENTS TO MANURE

In the following analysis of the results obtained in the first three years of these fertilizer tests, the yields for the lettuce crops and for the tomato crops are given separately. As previously stated, some treatments proved of benefit for one crop but detrimental to the other, and it is worth while to see just what these results were before considering the later tests designed to discover combination treatments beneficial to both crops.

The treatments given the different plots in this first series of tests are shown in Table 4.

### EFFECT OF TREATMENTS ON YIELDS OF LETTUCE

#### NITRATE OF SODA, DRIED BLOOD, ACID PHOSPHATE, AND POTASSIUM SULFATE TESTED SINGLY AND IN COMBINATION

The results of supplementing the 4-2-1 soil mixture with a single fertilizing element are shown in Table 5, which gives the total yields of lettuce from certain plots each year, together with the three-year average. The addition of nitrate of soda invariably increased the season's yield; and the addition of dried blood gave a marked increase

TABLE 4.—SOIL TREATMENT OF THE DIFFERENT PLOTS IN LETTUCE AND TOMATO EXPERIMENTS, 1918-1921

| Plot | Soil mixture[1] | Treatment |
|---|---|---|
| 51 | 4-2-1 | Check |
| 52 | 4-2-1 | Nitrate of soda |
| 53 | 4-2-1 | Dried blood |
| 54 | 4-2-1 | Acid phosphate |
| 55 | 4-2-1 | Potassium sulfate |
| 56 | 4-2-1 | Nitrate (double quantity) |
| 57 | 4-2-1 | Acid phosphate (double quantity) |
| 58 | 4-2-1 | Acid phosphate, lime |
| 59 | 4-2-1 | Acid phosphate, potassium sulfate |
| 60 | 4-2-1 | Acid phosphate, nitrate |
| 61 | 4-2-1 | Potassium sulfate, nitrate |
| 62 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate |
| 63 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) |
| 64 | 4-0-1 | Check |
| 65 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate |
| 66 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) |
| 67 | 4-4-1 | Check |
| 68 | 4-4-1 | Sterilized |
| 69 | 4-4-1 | Acid phosphate, potassium sulfate, nitrate |

[1]In this indication of the soil mixture the first figure refers to the proportion of *garden loam*, the second to the proportion of *manure*, and the last to the proportion of *sand*. These proportions were determined by *volume* rather than by weight.

in yield two seasons and a very slight decrease the third, with an average increase of 7½ pounds. On the other hand, the addition of acid phosphate or potassium sulfate resulted in a lower average yield.

When nitrogen was added as one of two fertilizing elements to the 4-2-1 soil mixture, the average yield for the three years was slightly increased, altho not so much as when nitrogen alone was used (Table

TABLE 5.—YIELDS OF LETTUCE: EFFECT OF ADDING DIFFERENT FERTILIZING ELEMENTS SINGLY TO A 4-2-1 SOIL MIXTURE

| Plot[1] | Treatment | 1918-19 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | Check | 56— 0 | 56— 8 | 49— 6 | 53—15 |
| 52 | Nitrate of soda | 62— 5 | 69—15 | 58—14 | 63—11 |
| 53 | Dried blood | 64—11 | 71—10 | 48— 0 | 61— 7 |
| 54 | Acid phosphate | 57—15 | 53— 6 | 47— 0 | 52—12 |
| 55 | Potassium sulfate | 57—12 | 51— 2 | 41—15 | 50— 4 |

[1]Each plot represents a bench area of approximately 24 square feet.

6). The use of a combination of acid phosphate and potassium sulfate resulted in a slightly larger yield one year and a very slightly larger three-year average. The complete fertilizer, composed of acid

TABLE 6.—YIELDS OF LETTUCE: EFFECT OF ADDING TWO OR MORE FERTILIZING ELEMENTS TO A 4-2-1 SOIL MIXTURE

| Plot | Treatment | 1918-19 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | Check | 56— 0 | 56— 8 | 49— 6 | 53—15 |
| 59 | Acid phosphate, potassium sulfate | 58—15 | 56— 6 | 48— 4 | 54— 8 |
| 60 | Acid phosphate, nitrate | 64— 2 | 61— 1 | 43— 2 | 56— 2 |
| 61 | Potassium sulfate, nitrate | 61— 9 | 67—14 | 38—13 | 56— 1 |
| 62 | Acid phosphate, potassium sulfate, nitrate | 52—14 | 66— 1 | 39— 7 | 52—13 |

phosphate, potassium sulfate, and nitrate of soda, gave a marked increase in yield one year but such small yields the other two years that the three-year average was below that of the check.

### LIME COUNTERACTS INJURIOUS EFFECT OF ACID PHOSPHATE

Since it was conceivable that acid phosphate might render the soil too acid for the best growing conditions for the lettuce, one plot was treated with lime in addition to the acid phosphate in order to compare the yields with those from the plot treated with acid phos-

TABLE 7.—YIELDS OF LETTUCE: EFFECT OF ADDING LIME TO PLOT OF 4-2-1 SOIL MIXTURE TREATED WITH ACID PHOSPHATE

| Plot | Treatment | 1918-19 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | Check | 56— 0 | 56— 8 | 49— 6 | 53—15 |
| 54 | Acid phosphate | 57—15 | 53— 6 | 47— 0 | 52—12 |
| 58 | Acid phosphate, lime | 58—14 | 58—12 | 56— 9 | 58— 1 |

phate alone. The plot to which lime was added outyielded the plain acid-phosphate plot every year (Table 7), and as an average for the three years showed more than 5 pounds increase in yield. It was also distinctly superior to the check plot, while the plot receiving the acid phosphate alone showed a lower average yield than the check.

### DOUBLING THE QUANTITY OF FERTILIZER LOWERS YIELD

In order to test the effect of supplying plant food in extra-large quantities, a few plots were treated with double the amounts used in most of the tests.

The double nitrate treatment gave lower yields than the normal nitrate treatment every year (Table 8), and as an average for the three years showed a decreased yield of nearly 11 pounds. The average yield from the double nitrate plot was lower than from the check plot.

TABLE 8.—YIELDS OF LETTUCE WHEN DOUBLE THE USUAL QUANTITIES OF FERTILIZERS WERE USED

| Plot | Soil mixture | Treatment | 1918-19 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|---|
| | | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | 4-2-1 | Check | 56— 0 | 56— 8 | 49— 6 | 53—15 |
| 52 | 4-2-1 | Nitrate | 62— 5 | 69—15 | 58—14 | 63—11 |
| 56 | 4-2-1 | Nitrate (double quantity) | 53— 5 | 65— 2 | 34— 1 | 52—15 |
| 54 | 4-2-1 | Acid phosphate | 57—15 | 53— 6 | 47— 0 | 52—12 |
| 57 | 4-2-1 | Acid phosphate (double quantity) | 58— 1 | 50— 1 | 46— 2 | 51— 7 |
| 62 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate | 52—14 | 66— 1 | 39— 7 | 52—13 |
| 63 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 53—14 | 59—10 | 32—15 | 48—13 |
| 65 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate | 45— 3 | 60— 5 | 45— 8 | 50— 5 |
| 66 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 42— 8 | 62—14 | 31—10 | 45—11 |

The double application of acid phosphate gave a slightly lower three-year average yield than the normal application; and both these treatments resulted in lower average yields than the check.

Doubling the quantity of the complete fertilizer (acid phosphate, potassium sulfate, and sodium nitrate), whether used on a soil containing manure or without manure, decreased the average yield as compared with the corresponding plots treated with the normal quantities of the same ingredients.

### COMPARISON OF THE THREE SOIL MIXTURES

The basic soil mixture used in most of the plots was composed of 4 parts garden loam, 2 parts rotted manure, and 1 part sand. However, three plots were included in which no manure was added to the

mixture of garden loam and sand, the formula being 4-0-1. A few plots also were included in which the soil mixture was composed of 4 parts garden loam, 4 parts rotted manure, and 1 part sand. For each of these soil mixtures there was an untreated check plot and a corresponding plot treated with acid phosphate, potassium sulfate, and sodium nitrate. In the case of the 4-2-1 mixture and also the 4-0-1 mixture, there was likewise a plot receiving a double treatment of these fertilizing materials. The yields from these various plots are given in Table 9.

TABLE 9.—YIELDS OF LETTUCE: COMPARISON OF THREE SOIL MIXTURES WITH AND WITHOUT SUPPLEMENTAL FERTILIZERS

| Plot | Soil mixture | Treatment | 1918-19 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|---|
| | | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | 4-2-1 | Check | 56— 0 | 56— 8 | 49— 6 | 53—15 |
| 62 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate | 52—14 | 66— 1 | 39— 7 | 52—13 |
| 63 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 53—14 | 59—10 | 32—15 | 48—13 |
| 64 | 4-0-1 | Check | 42— 0 | 42— 1 | 32— 3 | 38—12 |
| 65 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate | 45— 3 | 60— 5 | 45— 8 | 50— 5 |
| 66 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 42— 8 | 62—14 | 31—10 | 45—11 |
| 67 | 4-4-1 | Check | 54— 6 | 62—12 | 56— 9 | 57—14 |
| 69 | 4-4-1 | Acid phosphate, potassium sulfate, nitrate | 47— 0 | 69— 3 | 50— 5 | 55— 8 |

Of the check plots the one with the 4-4-1 mixture gave a distinctly larger yield than the 4-2-1 mixture in two of the three years, and as a three-year average showed nearly 4 pounds greater yield. The untreated 4-0-1 mixture showed an average yield which was approximately 19 pounds less than the 4-4-1 mixture and 15 pounds less than the 4-2-1 mixture.

Treatment with the complete fertilizer failed to increase the average yields from the 4-2-1 mixture and from the 4-4-1 mixture. However, the addition of a normal quantity of the complete fertilizer to the 4-0-1 mixture increased the yield every year, and showed a gain of more than 11 pounds as a three-year average.

The double quantity of complete fertilizer applied to the 4-0-1 mixture gave an increased yield two years of the three and an increase of approximately 7 pounds as a three-year average. However,

the 4-0-1 mixture with a complete fertilizer added, yielded less than the untreated 4-2-1 mixture or the untreated 4-4-1 mixture. Furthermore, the lettuce produced on the 4-0-1 mixture was of inferior quality, being of small size and tough in texture.

### STEAM STERILIZATION INCREASES YIELDS OF SECOND AND THIRD CROPS

Marked increases in yield were secured two years out of three from a plot of the 4-4-1 soil mixture which was sterilized[1] with steam before the planting of each crop of lettuce, that is, four times during each cropping season (Table 10.) The three-year average yield from

TABLE 10.—YIELDS OF LETTUCE: EFFECT OF STEAM STERILIZATION

| Plot | Treatment | 1918-19 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 67 | Check | 54— 6 | 62—12 | 56— 9 | 57—14 |
| 68 | Sterilized | 60— 0 | 72—11 | 54—14 | 62— 8 |

the sterilized plot was 4 pounds 10 ounces greater than from the corresponding unsterilized plot. The heavy crops of lettuce in the sterilized plots were distinctly different in appearance from any other lettuce in the house; the leaves were larger, coarser, and darker colored than the foliage of the other lettuce.

The increased yield from the sterilized plot was due largely to the especially heavy yields in the second and third crops each season. The fourth crop of the season was sometimes very light and disappointing. The repeated sterilizing seemed to render the plant food in the manure more quickly available, so that the supply was considerably depleted by the time the fourth crop was reached. However, the sterilizing did not, on the average, increase the yield in the first crop; the principal effect was on the second and third crops of the season.

## EFFECT OF TREATMENTS ON YIELDS OF TOMATOES

During the harvesting period the tomatoes were picked twice each week. Except in 1920, when a late start was secured on account of delay with the first crop of lettuce the fall before, the harvesting of the greenhouse tomatoes was completed by the time the main crop of outdoor tomatoes became abundant. The total yields of marketable

[1]The method of sterilization was as follows: A galvanized iron pan was inverted over the section of the bench to be sterilized, and live steam at a pressure of about 5 pounds was introduced under the pan by means of a rubber hose connected with a steam pipe in the heating system of the greenhouse. The treatment was continued for two hours.

tomatoes from the respective plots each year are given in the accompanying tables.

### NITRATE OF SODA, DRIED BLOOD, ACID PHOSPHATE, AND POTASSIUM SULFATE TESTED SINGLY AND IN COMBINATION

The effect upon tomato yields of supplementing the 4-2-1 soil mixture with a single element of plant food is indicated by the yields shown in Table 11.

TABLE 11.—YIELDS OF TOMATOES: EFFECT OF ADDING DIFFERENT FERTILIZING ELEMENTS SINGLY TO A 4-2-1 SOIL MIXTURE

| Plot | Treatment | Spring, 1919 | Spring, 1920 | Spring, 1921 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | Check | 58—13 | 45— 6 | 53—14 | 52—11 |
| 52 | Nitrate | 62— 4 | 53— 0 | 62—10 | 59— 4 |
| 53 | Dried blood | 63— 8 | 57— 1 | 64— 6 | 61—10 |
| 54 | Acid phosphate | 54— 8 | 54—10 | 61—13 | 57— 0 |
| 55 | Potassium sulfate | 51—14 | 46— 0 | 66— 8 | 54—13 |

The plot treated with nitrate of soda and the one treated with dried blood invariably gave larger yields than the untreated plot, the average increase apparently due to the nitrate treatment amounting to approximately 6½ pounds to the plot of 8 plants, and the increase in yield apparently due to the dried blood amounting to almost 9 pounds to the plot. The two plots receiving acid phosphate and potassium sulfate respectively showed increased yields two years out of the three, and increases also as an average for the three years.

The effects on the yields of greenhouse tomatoes obtained by adding more than one fertilizing element to the 4-2-1 soil mixture are indicated in Table 12. Wherever nitrogen was included in the fertilizer mixture, the average yields were markedly increased; and where nitro-

TABLE 12.—YIELDS OF TOMATOES: EFFECT OF ADDING TWO OR MORE FERTILIZING ELEMENTS TO A 4-2-1 SOIL MIXTURE

| Plot | Treatment | Spring, 1919 | Spring, 1920 | Spring, 1921 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | Check | 58—13 | 45— 6 | 53—14 | 52—11 |
| 59 | Acid phosphate, potassium sulfate | 61—14 | 44—13 | 50—14 | 52— 8 |
| 60 | Acid phosphate, nitrate | 67— 3 | 57— 0 | 67— 9 | 63—15 |
| 61 | Potassium sulfate, nitrate | 67— 2 | 42— 5 | 74—11 | 61— 6 |
| 62 | Acid phosphate, potassium sulfate, nitrate | 64— 0 | 52— 1 | 61—12 | 59— 4 |

gen was omitted, the average yield was slightly lowered. A comparison with the yields given in Table 11 shows also that the nitrate of soda used in conjunction with acid phosphate or potassium sulfate gave larger average yields of tomatoes than when nitrate of soda was used alone.

### ADDING LIME GIVES NO MATERIAL INCREASE IN YIELD

The addition of lime to the soil treated with acid phosphate did not materially increase the average yield of tomatoes as compared with the yield from the plot treated with acid phosphate alone (Table 13).

TABLE 13.—YIELDS OF TOMATOES: EFFECT OF ADDING LIME TO PLOT OF 4-2-1 SOIL MIXTURE TREATED WITH ACID PHOSPHATE

| Plot | Treatment | Spring, 1919 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | Check | 58—13 | 45— 6 | 53—14 | 52—11 |
| 54 | Acid phosphate | 54— 8 | 54—10 | 61—13 | 57— 0 |
| 58 | Acid phosphate, lime | 54—12 | 57— 2 | 60—11 | 57— 8 |

Both these plots, however, gave distinctly higher average yields than the check plot of the same kind of soil.

### DOUBLING THE QUANTITY OF FERTILIZER LOWERS YIELDS

A comparison of the yields of tomatoes from plots where the regular quantities of the fertilizing materials were used, with those from plots receiving double those quantities, is shown in Table 14. In no case was the average yield increased by doubling the quantity of fertilizer; in fact, it was distinctly smaller in three cases and slightly smaller in the other than the yield from the corresponding normally treated plot. The decrease in yield apparently due to the heavy fertilizing was especially marked in the case of the soil mixture which contained no manure.

### COMPARISON OF THE THREE SOIL MIXTURES

The check plots of the three different soil mixtures showed marked differences in yields of tomatoes, the increase in yield following the increase in the proportion of manure in the mixture (Table 15). The untreated 4-2-1 mixture gave an average yield of over 11 pounds more than the 4-0-1 mixture, while the 4-4-1 mixture gave an average of nearly 10 pounds more than the 4-2-1 mixture. The differ-

TABLE 14.—YIELDS OF TOMATOES WHEN DOUBLE THE USUAL QUANTITIES OF FERTILIZERS WERE USED

| Plot | Soil mixture | Treatment | Spring, 1919 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|---|
| | | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | 4-2-1 | Check | 58—13 | 45— 6 | 53—14 | 52—11 |
| 52 | 4-2-1 | Nitrate | 62— 4 | 53— 0 | 62—10 | 59—10 |
| 56 | 4-2-1 | Nitrate (double quantity) | 65— 0 | 46— 0 | 66— 5 | 59— 2 |
| 54 | 4-2-1 | Acid phosphate | 54— 8 | 54—10 | 61—13 | 57— 0 |
| 57 | 4-2-1 | Acid phosphate (double quantity) | 58— 3 | 46— 4 | 54— 9 | 53— 0 |
| 62 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate | 64— 0 | 52— 1 | 61—12 | 59— 4 |
| 63 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 56— 4 | 50— 2 | 62— 4 | 56— 3 |
| 65 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate | 67— 8 | 39— 8 | 54—14 | 53—15 |
| 66 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 58— 2 | 40— 6 | 31—12 | 43— 7 |

ence in average yield between the 4-0-1 mixture and the 4-4-1 mixture was 21 pounds and 8 ounces per plot, or more than 2½ pounds per plant. In other words, the heavily manured plot yielded over 50 percent more than the plot without manure.

When a complete fertilizer was added in normal amount, the response to the fertilizer treatment was greatest in the case of the soil without manure, on which the increase in average yield apparently due to the commercial fertilizers was nearly 13 pounds to the plot. The

TABLE 15.—YIELDS OF TOMATOES: COMPARISON OF THREE SOIL MIXTURES, WITH AND WITHOUT SUPPLEMENTAL FERTILIZERS

| Plot | Soil mixture | Treatment | Spring, 1919 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|---|
| | | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 51 | 4-2-1 | Check | 58—13 | 45— 6 | 53—14 | 52—11 |
| 62 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate | 64— 0 | 52— 1 | 61—12 | 59— 4 |
| 64 | 4-0-1 | Check | 44— 1 | 41—10 | 37— 4 | 41— 0 |
| 65 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate | 67— 8 | 39— 8 | 54—14 | 53—15 |
| 67 | 4-4-1 | Check | 71—14 | 52— 4 | 63— 7 | 62— 8 |
| 69 | 4-4-1 | Acid phosphate, potassium sulfate, nitrate | 70— 3 | 58—12 | 73— 2 | 67— 6 |

increase in average yield in the 4-2-1 mixture, apparently due to the same fertilizer treatment, was only 6 pounds and 9 ounces, or approximately half as much as in the case of the soil without manure. The commercial fertilizer gave a still smaller increase when added to the 4-4-1 mixture, the difference in average yield evidently due to the fertilizer treatment being only 4 pounds and 14 ounces for the plot.

### STEAM STERILIZATION REDUCES YIELD OF TOMATOES FOLLOWING FOUR CROPS OF LETTUCE

The yield of tomatoes from the sterilized plot was invariably lower than that from the unsterilized plot, the three-year average showing a difference of more than 15 pounds in favor of the unsterilized plot (Table 16). As mentioned in the discussion regarding the

TABLE 16.—YIELDS OF TOMATOES: EFFECT OF STEAM STERILIZATION

| Plot | Treatment | Spring, 1919 | 1919-20 | 1920-21 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.— oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 67 | Check | 71—14 | 52— 4 | 63— 7 | 62— 8 |
| 68 | Sterilized | 46— 3 | 51— 2 | 43— 6 | 46—14 |

lettuce on the sterilized plot, this treatment seemed to render the plant food in the soil mixture more quickly available, so that it was drawn upon very heavily by the second and third crops of lettuce. This sometimes left little available plant food for the fourth crop of lettuce and the crop of tomatoes following the lettuce on the sterilized plot.

### COMBINED YIELDS OF LETTUCE AND TOMATOES

Since it is desirable to know the total yield of greenhouse crops from a given bench area during the greenhouse cropping season, the average yields of lettuce and marketable tomatoes per season from each plot or bench section have been calculated in terms of pounds per square foot of bench area (Table 17). The average total yield of lettuce and tomatoes combined is also given.

The lettuce and tomatoes were sold at wholesale to merchants in Champaign and Urbana. The price received for the lettuce ranged from 12½ to 25 cents a pound, averaging slightly over 20 cents. Twenty cents a pound was approximately the average price received for the tomatoes also; they sold at 25 cents a pound early in the season, 20 cents later on, and finally at 15 cents after the local early outdoor crop was supplying the market. At 20 cents a pound for both crops, four plots yielded a gross income of more than one

TABLE 17.—YIELDS OF LETTUCE AND TOMATOES PER SQUARE FOOT OF BENCH SPACE
(Three-year average, 1918-1921)

| Plot | Soil mixture | Treatment | Lettuce | Tomatoes | Total | Total sales per square foot |
|---|---|---|---|---|---|---|
| | | | *lbs.* | *lbs.* | *lbs.* | |
| 51 | 4-2-1 | Check | 2.24 | 2.19 | 4.43 | $ .886 |
| 52 | 4-2-1 | Nitrate | 2.65 | 2.47 | 5.12 | 1.024 |
| 53 | 4-2-1 | Dried blood | 2.56 | 2.57 | 5.13 | 1.026 |
| 54 | 4-2-1 | Acid phosphate | 2.19 | 2.37 | 4.56 | .912 |
| 55 | 4-2-1 | Potassium sulfate | 2.09 | 2.28 | 4.37 | .874 |
| 56 | 4-2-1 | Nitrate (double quantity) | 2.20 | 2.46 | 4.66 | .932 |
| 57 | 4-2-1 | Acid phosphate (double quantity) | 2.14 | 2.21 | 4.35 | .870 |
| 58 | 4-2-1 | Acid phosphate, lime | 2.42 | 2.39 | 4.81 | .962 |
| 59 | 4-2-1 | Acid phosphate, potassium sulfate | 2.27 | 2.18 | 4.45 | .890 |
| 60 | 4-2-1 | Acid phosphate, nitrate | 2.33 | 2.66 | 4.99 | .998 |
| 61 | 4-2-1 | Potassium sulfate, nitrate | 2.33 | 2.55 | 4.88 | .976 |
| 62 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate | 2.20 | 2.47 | 4.67 | .934 |
| 63 | 4-2-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 2.03 | 2.34 | 4.37 | .874 |
| 64 | 4-0-1 | Check | 1.61 | 1.71 | 3.32 | .664 |
| 65 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate | 2.09 | 2.24 | 4.33 | .866[1] |
| 66 | 4-0-1 | Acid phosphate, potassium sulfate, nitrate (double quantities) | 1.90 | 1.81 | 3.71 | .742 |
| 67 | 4-4-1 | Check | 2.41 | 2.60 | 5.01 | 1.002 |
| 68 | 4-4-1 | Sterilized | 2.60 | 1.95 | 4.55 | .910 |
| 69 | 4-4-1 | Acid phosphate, potassium sulfate, nitrate | 2.31 | 2.81 | 5.12 | 1.024 |

[1]Altho the total sales from this plot were almost as much as from the 4-2-1 check plot, the quality of lettuce was decidedly inferior. If it had been marketed alone, the returns would have been less than indicated here.

dollar for each square foot of bench space, and the fifth plot yielded almost one dollar a square foot, while the poorest plot (the check plot without manure or fertilizer) yielded products worth only a fraction more than 66 cents a square foot.

The lettuce and tomatoes did not respond equally well to the same fertilizer treatment (Table 17). The lettuce responded especially well to nitrogen alone, whether it was supplied by means of sodium nitrate, dried blood, heavy manuring, or steaming of the heavily manured soil. Acid phosphate seemed to be detrimental to the lettuce crop unless supplemented by lime or sodium nitrate; and even then the yields were less than from the use of nitrate alone. The complete fertilizer, consisting of acid phosphate, potassium sulfate, and sodium nitrate, apparently reduced the yields of lettuce, except on the soil which contained no manure.

On the other hand, the tomatoes, while responding quite favorably to the nitrogen treatment, gave considerably higher yields where the nitrate was supplemented with acid phosphate, and the highest yield of all where the complete fertilizer was used on the plot already heavily manured. Reasonable quantities of acid phosphate, whether used alone or in combination, apparently were not detrimental to the tomato crop.

It would appear from these results that no acid phosphate should be used for the lettuce crop, except possibly in combination with lime, and that acid phosphate used with plenty of nitrogen is a very desirable combination for the production of good crops of greenhouse tomatoes. In view of these circumstances, additional tests were planned for the purpose of finding, if possible, a method of fertilizing that would be highly beneficial to both crops. These further tests are discussed in the following pages.

## TESTS TO FIND COMBINATION TREATMENTS EFFECTIVE FOR BOTH LETTUCE AND TOMATOES

To obviate the harmful effect of acid phosphate on lettuce noted in the preceding experiments, and yet furnish phosphorus for the succeeding tomato crop, three methods of supplying this plant food were compared: (1) lime was applied along with the acid phosphate; (2) steamed bone meal was substituted for acid phosphate; and (3) acid phosphate was applied as a top-dressing to the tomatoes after the last crop of lettuce was harvested.

In the earlier tests steam sterilization of the soil, while resulting in heavy initial crops of lettuce, seemed to effect such depletion of the soil that the fourth crop of lettuce and the crop of tomatoes were sometimes greatly reduced. An effort was made to overcome this dif-

ficulty by applying nitrate for the fourth crop of lettuce, and then using a top-dressing of acid phosphate for the tomatoes.

A mixture of acid phosphate and potassium sulfate also was tested as a top-dressing for the tomato crop. Other tests were included to compare further nitrate of soda and dried blood as sources of nitrogen for the crops in question.

The kinds of soil mixture used in the various sections, or plots, and the soil treatments applied are given in Table 18.

TABLE 18.—SOIL TREATMENT OF THE DIFFERENT PLOTS IN LETTUCE AND TOMATO EXPERIMENTS, 1921-1924

| Plot | Soil mixture | Treatment |
|---|---|---|
| 71 | 4-2-1 | Check |
| 72 | 4-2-1 | Nitrate of soda |
| 73 | 4-2-1 | Dried blood |
| 74 | 4-2-1 | Acid phosphate, lime |
| 75 | 4-2-1 | Acid phosphate, lime, nitrate |
| 76 | 4-2-1 | Steamed bone, nitrate |
| 77 | 4-2-1 | Acid phosphate, lime, potassium sulfate, nitrate |
| 78 | 4-2-1 | Nitrate for lettuce, acid phosphate for tomatoes |
| 79 | 4-2-1 | Dried blood for lettuce, acid phosphate for tomatoes |
| 80 | 4-2-1 | Nitrate for lettuce, acid phosphate and potassium sulfate for tomatoes |
| 81 | 4-4-1 | Check |
| 82 | 4-4-1 | Sterilized |
| 83 | 4-4-1 | Sterilized; nitrate for fourth crop lettuce, acid phosphate for tomatoes |
| 84 | 4-4-1 | Nitrate for lettuce, acid phosphate and potassium sulfate for tomatoes |

The initial applications of fertilizer and the top-dressings of nitrate were made in the same manner as in the preceding tests. The top-dressings for the tomatoes (acid phosphate, and acid phosphate and potassium sulfate) were made immediately after the fourth crop of lettuce was harvested from among the tomato plants. The materials were sprinkled over the surface of the soil and worked in lightly by means of a hand weeder. Care was taken to avoid letting any of the fertilizers come in direct contact with the stems or roots of the plants.

## EFFECT OF DIFFERENT METHODS OF APPLYING PHOSPHORUS

The combination of steamed bone and nitrate did not result in as high yields of lettuce as an average for the three years as the acid phosphate with nitrate and lime (Table 19). The latter combination gave slightly better yields than the average of the three nitrate plots,

TABLE 19.—YIELDS OF LETTUCE: COMPARISON OF EFFECT OF ACID PHOSPHATE AND STEAMED BONE ADDED TO A 4-2-1 SOIL MIXTURE

| Plot | Treatment | 1921-22 | 1922-23 | 1923-24 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 71 | Check | 50—12 | 42— 9 | 56— 8 | 49—15 |
| 74 | Acid phosphate, lime | 52— 6 | 47— 2 | 60—11 | 53— 6 |
| 75 | Acid phosphate, lime, nitrate | 61—11 | 53— 8 | 69—12 | 61—10 |
| 76 | Steamed bone, nitrate | 55—10 | 56—12 | 59—10 | 57— 5 |
| | Average of 3 nitrate plots, without phosphorus (72, 78, 80) | 57— 1 | 55—13 | 64—14 | 59— 4 |

while the yields from steamed bone and nitrate averaged slightly less than the yields from the plots treated with nitrate alone.

The combined treatment of acid phosphate, lime, and nitrate gave much better average yields of tomatoes than the lime and acid phosphate (Table 20). The top-dressing of acid phosphate to the tomatoes, following nitrate treatment for the lettuce, gave still better results. Where dried blood had been used as a source of nitrogen for the lettuce, the top-dressing of acid phosphate for the tomatoes did not appear to be effective.

TABLE 20.—YIELDS OF TOMATOES: EFFECT OF DIFFERENT METHODS OF SUPPLYING PHOSPHORUS TO A 4-2-1 SOIL MIXTURE

| Plot | Treatment | 1921-22 | 1922-23 | 1923-24 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 71 | Check | 56— 2 | 71—15 | 70— 0 | 66— 0 |
| 74 | Acid phosphate, lime | 45— 0 | 73— 3 | 58—14 | 59— 0 |
| 75 | Acid phosphate, lime, nitrate | 59—12 | 72— 3 | 75—12 | 69— 3 |
| 76 | Steamed bone, nitrate | 69— 6 | 80— 5 | 73— 2 | 74— 4 |
| 77 | Acid phosphate, lime, potassium sulfate, nitrate | 62— 7 | 69— 9 | 82—11 | 71— 9 |
| 78 | Nitrate for lettuce, acid phosphate for tomatoes | 71—13 | 69— 7 | 75— 7 | 72— 3 |
| 79 | Blood for lettuce, acid phosphate for tomatoes | 51— 0 | 67—15 | 62— 0 | 60— 5 |
| 80 | Nitrate for lettuce, acid phosphate and potassium sulfate for tomatoes | 55— 1 | 62— 9 | 72—13 | 63— 7 |

The highest yield of tomatoes, as an average for the three years, was secured from the plot treated with steamed bone and nitrate for the lettuce, with no additional treatment for the tomatoes. The addition of potassium sulfate as a top-dressing along with the acid phosphate seemed to reduce the yield.

## TOP-DRESSINGS APPLIED TO LAST CROPS REDUCE LOSSES FROM STEAM STERILIZATION

In the previous tests steam sterilization of the soil before the planting of each lettuce crop seemed to result in such depletion of the soil as to reduce the fourth crop of lettuce and the crop of tomatoes following. A test was therefore made to determine the effect of the addition of nitrate to the sterilized soil just before planting the fourth crop, and of acid phosphate following the harvest of the lettuce.

TABLE 21.—YIELDS OF LETTUCE: EFFECT OF STEAM STERILIZATION

| Plot | Treatment | 1921-22 | 1922-23 | 1923-24 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 81 | Check | 54— 5 | 54— 9 | 58—13 | 55—14 |
| 82 | Sterilized | 67— 0 | 58—11 | 68—13 | 64—13 |
| 83 | Sterilized; nitrate for 4th crop | 70— 8 | 60—15 | 66— 0 | 65—13 |
| 84 | Nitrate | 61—10½ | 59—11 | 69— 5 | 63— 8 |

Steam sterilization distinctly increased the total yield of lettuce each year, and in two years out of the three the application of nitrate of soda for the fourth crop made a slight additional increase (Table 21). Each year the fourth crop was slightly larger from the plot that was treated with nitrate preceding the planting of that crop. However, the fourth crop of lettuce was not reduced by the sterilization of the soil, as it was in the preceding test.

TABLE 22.—EFFECT OF STEAM STERILIZATION ON TOMATO CROP FOLLOWING LETTUCE

| Plot | Treatment | 1922 | 1923 | 1924 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 81 | Check | 55— 2 | 68—10 | 59—12 | 61— 2 |
| 82 | Sterilized | 37—15 | 38— 3 | 54— 9 | 43— 9 |
| 83 | Sterilized, nitrate for 4th crop of lettuce, acid phosphate for tomatoes | 47— 9 | 50— 7 | 61—12 | 53— 4 |
| 84 | Nitrate for lettuce, acid phosphate and potassium sulfate for tomatoes | 71— 3 | 71—15 | 72—14 | 72— 0 |

The depleting effect of steam sterilization on the soil during the production of the four lettuce crops was apparent in the tomato crop following the lettuce (Table 22). The sterilized plot without supple-

mentary treatment yielded a much smaller crop of tomatoes, as an average for three years, than the untreated plot. Top-dressings of sodium nitrate applied before the last crop of lettuce, and of acid phosphate to the tomatoes, partially overcame this depleted condition, but still the average yield of the plot so treated was less than the yield of the check plot.

Top-dressings of acid phosphate and potassium sulfate applied to the unsterilized soil of the same composition, following treatment with nitrate of soda for the lettuce, gave a decided increase in yield.

### SODIUM NITRATE AND DRIED BLOOD ABOUT EQUAL IN VALUE AS SOURCES OF NITROGEN FOR LETTUCE

Each year both sodium nitrate used alone and dried blood used alone gave distinct increases in yields of lettuce, as compared with the check plot (Table 23). While the average yields from the plots treated

TABLE 23.—YIELDS OF LETTUCE: COMPARISON OF EFFECT OF SODIUM NITRATE AND DRIED BLOOD ADDED TO A 4-2-1 SOIL MIXTURE

| Plot | Treatment | 1921-22 | 1922-23 | 1923-24 | 3-year average |
|---|---|---|---|---|---|
| | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 71 | Check | 50—12 | 42— 9 | 56— 8 | 49—15 |
| 72 | Nitrate | 58— 5 | 47—15 | 64— 5 | 56—13 |
| 78 | Nitrate | 57—13 | 60— 8 | 64— 3 | 60—13 |
| 80 | Nitrate | 55— 3 | 59— 1 | 66— 2 | 60— 2 |
| | Average of 3 nitrate plots | 57— 1 | 55—13 | 64—14 | 59— 4 |
| 73 | Dried blood | 62—13 | 53—15 | 65— 2 | 60—10 |
| 79 | Dried blood | 59— 8 | 61—10 | 64— 1 | 61—11 |
| | Average of 2 dried blood plots | 61— 2 | 57—12 | 64— 9 | 61— 2 |

with blood were slightly higher for the three-year period than those from plots treated with nitrate, the data in Table 5 indicate that for the preceding three-year period the average yields were slightly better from the nitrated plot. If a six-year average is taken, the yields are approximately the same from the plots treated with nitrate and from those treated with dried blood.

### TWO SOIL MIXTURES COMPARED, WITH AND WITHOUT NITRATE

The 4-4-1 soil mixture (4 parts each of loam and manure and 1 part sand) gave larger yields of lettuce every year than the 4-2-1 mixture, when neither soil was supplemented with additional nitrogen

TABLE 24.—YIELDS OF LETTUCE: COMPARISON OF EFFECT OF TWO DIFFERENT SOIL MIXTURES

| Plot | Soil mixture | Treatment | 1921-22 | 1922-23 | 1923-24 | 3-year average |
|---|---|---|---|---|---|---|
| | | | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* | *lbs.—oz.* |
| 71 | 4-2-1 | Check | 50—12 | 42— 9 | 56— 8 | 49—15 |
| 81 | 4-4-1 | Check | 54— 5 | 54— 9 | 58— 13 | 55—14 |
| 72 | 4-2-1 | Nitrate | 58— 5 | 47—15 | 64— 5 | 56—13 |
| 78 | 4-2-1 | Nitrate | 57—13 | 60— 8 | 64— 3 | 60—13 |
| 80 | 4-2-1 | Nitrate | 55— 3 | 59— 1 | 66— 2 | 60— 2 |
| | | Average of 3 nitrate plots | 57— 2 | 55—13 | 64—14 | 59— 4 |
| 84 | 4-4-1 | Nitrate | 61—10 | 59—11 | 69— 5 | 63— 8 |

(Table 24). The addition of nitrate to both soils distinctly increased the yields, the 4-2-1 mixture with the addition of nitrate giving larger yields than the 4-4-1 mixture without nitrate. However, the largest yields of all were secured from the 4-4-1 mixture treated with nitrate. These results emphasize the importance of liberal supplies of nitrogen for the lettuce crop.

## COMBINED YIELDS OF LETTUCE AND TOMATOES

In order to determine the total yield of lettuce and tomatoes for the greenhouse cropping season, the yields have been reduced to terms of pounds per square foot of bench space (Table 25).

The products from the greenhouse in 1921 to 1924 were sold at wholesale to merchants in Champaign and Urbana. The price of lettuce varied from 12½ to 23 cents a pound, and the tomatoes were sold at 15 to 20 cents a pound. The value of the crops per square foot of bench space has been calculated on the basis of 18 cents a pound (Table 25).

The value of the combined crop averaged more than one dollar per square foot of bench space for the highest yielding plot, in spite of the lower price of products in this period as compared with the preceding three-year period. Several other plots produced crops to the value of almost one dollar per square foot of bench space.

On the 4-2-1 soil mixture acid phosphate and lime used with nitrate produced a satisfactory crop of lettuce and a good crop of tomatoes. Slightly better results in combined yields of the two crops, however, were secured when the nitrate was used alone for the lettuce and the acid phosphate applied as a top-dressing for the tomatoes after the last crop of lettuce was harvested. The use of steamed bone with nitrate resulted in the largest crop of tomatoes, but was less favorable to the production of lettuce than the nitrate and acid phosphate.

TABLE 25.—YIELDS OF LETTUCE AND TOMATOES PER SQUARE FOOT OF BENCH SPACE
(Three-year average, 1922-1924)

| Plot | Soil mixture | Treatment | Yield per square foot | | | Total sales per square foot |
|---|---|---|---|---|---|---|
| | | | Lettuce | Tomatoes | Total | |
| | | | *lbs.* | *lbs.* | *lbs.* | |
| 71 | 4-2-1 | Check | 2.08 | 2.75 | 4.83 | $ .869 |
| 72 | 4-2-1 | Nitrate of soda | 2.36 | 2.69 | 5.05 | .909 |
| 73 | 4-2-1 | Dried blood | 2.52 | 2.83 | 5.35 | .963 |
| 74 | 4-2-1 | Acid phosphate, lime | 2.22 | 2.46 | 4.68 | .842 |
| 75 | 4-2-1 | Acid phosphate, lime, nitrate | 2.56 | 2.88 | 5.44 | .979 |
| 76 | 4-2-1 | Steamed bone, nitrate | 2.38 | 3.09 | 5.47 | .984 |
| 77 | 4-2-1 | Acid phosphate, lime, potassium sulfate, nitrate | 2.40 | 2.98 | 5.38 | .968 |
| 78 | 4-2-1 | Nitrate for lettuce, acid phosphate for tomatoes | 2.53 | 3.00 | 5.53 | .995 |
| 79 | 4-2-1 | Dried blood for lettuce, acid phosphate for tomatoes | 2.56 | 2.51 | 5.07 | .912 |
| 80 | 4-2-1 | Nitrate for lettuce, acid phosphate and potassium sulfate for tomatoes | 2.50 | 2.64 | 5.14 | .925 |
| 81 | 4-4-1 | Check | 2.32 | 2.54 | 4.86 | .874 |
| 82 | 4-4-1 | Sterilized | 2.70 | 1.81 | 4.51 | .811 |
| 83 | 4-4-1 | Sterilized; nitrate for 4th crop, acid phosphate for tomatoes | 2.74 | 2.21 | 4.95 | .891 |
| 84 | 4-4-1 | Nitrate for lettuce, acid phosphate and potassium sulfate for tomatoes | 2.64 | 3.00 | 5.64 | 1.015 |

On the whole, it appears that in growing lettuce and tomatoes in a 4-2-1 soil mixture, the beneficial effects of phosphorus on the tomato crop, without detriment to the lettuce, can be secured most readily *by using nitrate alone for the lettuce and applying acid phosphate as a top-dressing for the tomatoes after the last crop of lettuce has been harvested.*

Sterilization of the 4-4-1 soil mixture resulted in the heaviest crops of lettuce, but so depleted the soil that, in spite of the top-dressings of sodium nitrate and acid phosphate, the yields of tomatoes were much reduced. The unsterilized 4-4-1 mixture treated with nitrate for the lettuce and supplemented with a top-dressing of acid phosphate and potassium sulfate for the tomatoes, produced a large crop of tomatoes and the largest combined yield of tomatoes and lettuce.

### COST OF FERTILIZER RELATIVELY SMALL

The question of the relative costs of the different fertilizer treatments, so far as the commercial fertilizers are concerned, is unimportant, for at the prices of fertilizing materials in 1924, the cost of the most expensive treatment was less than ½ cent a square foot. The expense for commercial fertilizer, therefore, is almost negligible as a factor in the cost of producing greenhouse lettuce and tomatoes, when the original cost of the greenhouse and equipment, the upkeep of the plant, and the fuel and labor involved in producing the crop are considered.

Less than ½ cent for supplementary fertilizer for a crop that will probably be worth nearly a dollar is a very small item in the cost of production, and the relative costs of different commercial fertilizers need not be considered in comparing their merits.

## CONCLUSIONS

1. It does not seem feasible to grow greenhouse lettuce and tomatoes on raised benches of brown silt loam without the use of manure. Not only are the yields light, but the quality of lettuce is poor where no manure is used.

2. Satisfactory crops of greenhouse lettuce and tomatoes may be grown in a soil mixture of 4 parts brown silt loam, 2 parts rotted manure, and 1 part sand by properly supplementing this mixture with commercial fertilizers.

3. Greenhouse lettuce responds readily to nitrogen treatment. Nitrate of soda or dried blood will give excellent results in supplementing the plant-food materials in a 4-2-1 soil mixture. Nitrate will even increase the yield of lettuce on a rich soil mixture composed of 4 parts loam, 4 parts rotted manure, and 1 part sand.

4. When used on a 4-2-1 soil mixture, acid phosphate is detrimental to the lettuce crop unless it is used in combination with lime, but is beneficial to the tomato crop, especially when used in combination with nitrate. The beneficial effect on the tomatoes may be secured without danger of detriment to the lettuce by applying the acid phosphate as a top-dressing for the tomatoes after the last crop of lettuce has been harvested. Such fertilization, combined with the use of sodium nitrate in the production of the lettuce, results in conditions favorable for the production of both crops.

5. Potassium sulfate appears to be of no particular importance in the fertilizing of greenhouse lettuce, but may be of some benefit to greenhouse tomatoes, when used in combination with sodium nitrate or nitrate and acid phosphate.

6. If excessive quantities of commercial fertilizers are used, the yields of both lettuce and tomatoes are likely to be reduced.

7. Since the cost of commercial fertilizer is an insignificant item in the cost of production of greenhouse lettuce and tomatoes, the use of such materials as will increase the yields is fully warranted.

8. Sterilizing a heavily manured soil by the use of steam before each crop of lettuce is planted stimulates an enormous growth of lettuce, especially in the second and third crops, but results in such exhaustion of the soil that the succeeding crop of tomatoes is likely to be small.

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